January 11th, 2008

Occupational Safety and Health Standards Board
California Department of Industrial Relations
2520 Ventura Oaks Way, Suite 350
Sacramento, CA 95833

RE: Petition to Amend Reference to "200 feet" in Title 8:

1. Subchapter 4, Article 10, §1592. Warning Methods.
2. Subchapter 7, Group 4, Article 27, §3706. Truck Warning Device.
3. Subchapter 7, Group 4, Article 31, §3801. Warning Devices.
4. Subchapter 17, Article 17, §7016. Haulage Vehicle, Construction and Maintenance.
5. Subchapter 17, Article 17, §7024. Mine Trains – Equipment and Practice.
6. Subchapter 20, Article 17, §8483. Haulage and Earthmoving Equipment.
7. Others § that may exist that have not been identified.

This petition to amend and update the above referenced Orders is being submitted by Brigade Electronics Inc, a subsidiary of Brigade Electronics Plc ("Brigade") based in the UK. Brigade, operating since 1975, is a leading developer of back-up safety systems with many UK, European and global firsts and it has been called on by associations and government departments around the world for advice. "Brigade" has offices in the UK, USA, Germany, Italy, Greece and South Africa and is currently finalising arrangements for offices in Holland and France.

Summary

"Brigade" has identified a requirement in the Cal/OSHA regulations that works directly against safety; the requirement for back-up alarms to be heard at 200 feet from the vehicle. This requirement for audibility at 200 feet is inconsistent with many academic papers and corporate best practice standards and is already becoming a problem for companies that have adopted best practice and technology outside California being prevented by the 200 feet requirement from doing so in California.

This 200 feet requirement generates four specific problems; false alarms; increasing site noise; exclusion of new technology; and prevention of universal adoption of best practice by national and international companies.

1. False alarms. "False alarms negatively impact safety" Dr. Gary W. Hunter, Dr. Jennifer C. Xu, and Robert C. McKnight; Aviation Safety, CEV, Life Support & Habitation, NASA. A false alarm is an alarm heard outside the hazard zone. The hazard zone is the area in which the alarm needs to be alerting. There is a relationship between the false alarm and response rates, the higher the false alarm rate, the lower the response rate. Some research suggests a direct

inverse proportionality between false alarm rate and response rate (e.g.; 43% false alarm rate achieves 57% response rate). For most back-up alarm applications the hazard zone is a rough 1/3 arc between just 10 feet to 50 feet to the rear of the vehicle. A back-up alarm alerting people at 200 feet in all directions gives a massive false alarm rate of 95% or more. Examples of hazard areas and false alarm rate calculations are at Exhibit "A"

2. Increase in Site Noise. Localization of the sound source can be very important in construction. Workers need to be aware of warning signals, shouts from co-workers, and back-up alarms from moving vehicles[1]. Unnecessarily loud back-up alarms adds to the decibel competition between various on-site acoustic demands and directly contribute to increasing noise levels and reduce safety.

3. New Technology. New technology is prevented from being adopted. BroadBand Sound back-up alarms, for instance, not only greatly reduce the false alarm zone but also, for equal audibility/loudness, have lower sound pressure levels. They are also more meaningful to the hard of hearing, are less likely to be masked by other sounds, eliminate standing waves which cause confusion and get rid of noise nuisance, resultant complaints and intentional disconnects.

4. Best Practice. Most major mining companies in the USA now use BroadBand back-up alarms in part of their operation, the trend if of increasing demand. A few international companies already specify BroadBand alarms to both improve safety and for reasons of social and environmental responsibility.

The wording in each article is similar:

§1592 *The warning sound shall be of such magnitude that it will normally be audible from a distance of 200 feet*

§3706 *a warning device which can be clearly heard for a distance of 200 feet from the vehicle*

§3801 *an effective warning device audible for 200 feet from the front and the rear of the truck*

§7016 *all be equipped with a warning device which can be clearly heard for a distance of 200 feet from the vehicle.*

§7024 *shall be provided with an audible warning device capable of being heard at a distance of 200 feet*

§8483 *which would normally be audible from a distance of 200 feet*

[1] Construction Noise: Exposure, Effects, and the Potential for Remediation; A Review and Analysis, Alice H. Suter AIHA Journal 63:768–789 (2002)

Proposed Action

The petitioner proposes a revision to §1592, §3706, §3801, §7016, §7024, §8483 and any others not identified to provide both consistency within the standards and safer requirements as follows:

> *A truck automatic back-up warning sound shall be clearly alerting in all parts of and close to the hazard area. If possible the sound should be locatable and contained close to the hazard area.*

First Sentence. The use of the word "alerting" best describes the requirement for the alarm; an "audible" alarm need not be one loud enough to attract the attention of someone busy at work. This would greatly reduce false alarm rates, allow new technologies and companies to have a global standard.
Second Sentence (in red). This would encourage operators to consider other benefits.

False Alarms

A large body of literature exists that addresses the effects of false alarms on human operators. The large majority of works concentrate on systems that are not directly relevant to back-up alarms; nevertheless these works offer insights into far-reaching effects of false back-up alarm warning. Some references and other information in support of the need to minimise false alarm warnings are listed below:

1. *Boy Cried Wolf*
2. *"The effect of false alarms on human trust in warning systems and on credibility of warnings could be considerable even for low false alarm rates."*

   "False Alarms and Human-Machine Warning Systems"
   UC Berkeley Traffic Safety Center, (University of California, Berkeley)
   Aleksandr A. Zabyshny & David R. Ragland.

3. *"Pedestrians become habituated to the alarm and ignore it, because it constantly sounds a meaningless warning."*

   Toyota Industrial Equipment Accessories Brochure 35158

4. *BBS White Paper Rev4 CONSULTATION DRAFT (Exhibit* B*).*

   Brigade Electronics

5. *"False alarms are of no use to anyone, serving only to increase the noise levels within that environment. With regard to safety, they will over time become less effective as people (sub-consciously) match their response level to the false alarm rate".*

   Bliss et al, 1995

Tonal Back-Up Alarms

Only tonal alarms can meet the 200 feet requirement. Tonal alarms are not particularly good in doing the task for which they were designed. They:

1) Generate standing waves which cause confusion
2) Suffer from reflections which add to the confusion
3) Are tonal and so strident
4) Risk being masked by similar frequencies
5) Risk not being heard by someone with hearing damage in the tonal alarm's frequency.

A "fault tree analysis" can be used to identify the reason why a back-up accident occurred. Exhibit "C" to this petition gives an atypical analysis; it shows that provided an alarm of the correct loudness is fitted then accidents resulting from an ineffective alarm are all due to the tonal nature of the alarm. These are in red below:

1. Back-Up Alarm Faulty
    a. Intentional Disconnect
        i. Caused Irritation to Neighbors
        ii. Caused Irritation to Driver
    b. Not ……
2. Back-Up Alarm Ineffective
    a. Not loud enough above ambient
    b. Tuned out
        i. Not Recognised as Danger Warning Signal
            1. Associated with Backing Vehicle Somewhere
            2. Not loud enough
        ii. Inattention Due to Habituation
    c. Caused Confusion
            1. Thought Danger was Elsewhere
            2. Could Not Quickly Locate Danger
            3. Too loud
    d. Could Not Be Heard Due to Deafness in Alarm Frequency Range
    e. Could Not Be Heard Due to Alarm Frequency Being Masked By Other Sound

BroadBand Sound Back-Up Alarms

BroadBand back-up alarms provide the following benefits.

1. Improved safety:
    a. Locatable sound
    b. Better response
    c. Not confusing
    d. Reduced risk of alarm sound being masked
    e. Reduced risk of inaudibility by hard of hearing
    f. Less distracting
    g. Alleviate intentional disconnects

2. Environment - reduces ambient noise:
    a. Greater acceptance
    b. Better concentration
3. Health:
    a. Less stress
    b. Reduced risk of long term hearing damage

Finally

BroadBand alarms are already being used in California by mining, landfill and waste operators.

BroadBand alarms are already being specified by cities; New York & Seattle (Maricopa County and North Dakota DOT expected shortly).

BroadBand alarms are already being used by leading companies a few examples are:

> USA; Port of Houston, majority of largest mining companies for both on and off highway use (eg; Glacier Northwest (California Portland Cement Company), N Dakota DOT, Republic Waste, Waste Management, ...
>
> EU; British Airports Authority, London Buses, TNT, Lynx (part of UPS), ASDA (part of Wal-Mart), City of London, recommended for safety by the Quarry Products Association (UK equiv to NSSGA), ...

The petitioner would note that this is a specialist area requiring safety engineering, acoustic and psychoacoustic knowledge. Brigade spends significant resource helping to develop scientific knowledge and improve technology. Given the challenge of ensuring the safety of staff and public near working mobile plant and trucks, we believe that the proposed change will help reduce back-up accidents and improve acceptance of back-up alarms.

In closing, we express our appreciation to the California Occupational Safety and Health Standards Board for considering this petition, and we look forward to the opportunity to respond to any inquiries of the Board, the Division of Occupational Safety and Health, or any designated advisory committee.

Henry Morgan
Director and General Manager
Brigade Electronics Inc

Enclosures:
    Exhibit “A” – Examples of Hazard Areas & Calculations.
    Exhibit "B" – BBS White Paper Rev4 CONSULTATION DRAFT
    Exhibit "C" – Fault Tree Analysis.

Exhibit "A"

Examples of Hazard Areas & False Alarm Rate Calculations

Numerous factors need to be taken in to account in determining a hazard area. It is not an exact science and in most operations experience invariably helps determine the hazard zone. The back-up hazard can be reduced by management controls such as prohibiting backing in certain areas or applying speed controls. Factors for consideration include:

1) Speeds of backing straight and at different turning angles
2) Turning circle
3) The people likely to be exposed; own training staff; other contracts or public
4) Level of control over those who may be in hazard area
5) Site/driver speed regulations
6) Site operating regulations
7) Visibility
8) Surrounding noise levels and noise sources
9) Site layout
10) Vehicle braking distances
11) Driver reaction time

Two illustrative examples of hazard zones are given below; Truck A (perhaps a wheel loader Figures 1) and Truck B (perhaps a concrete truck Figures 2). The speeds that need consideration are; (a) pedestrian potential "walk-in" speeds (SA1 & BA1); (b) truck backing on full lock (SA2 & BA2) and; maximum likely/permitted backing speed (SA3 & BA3).

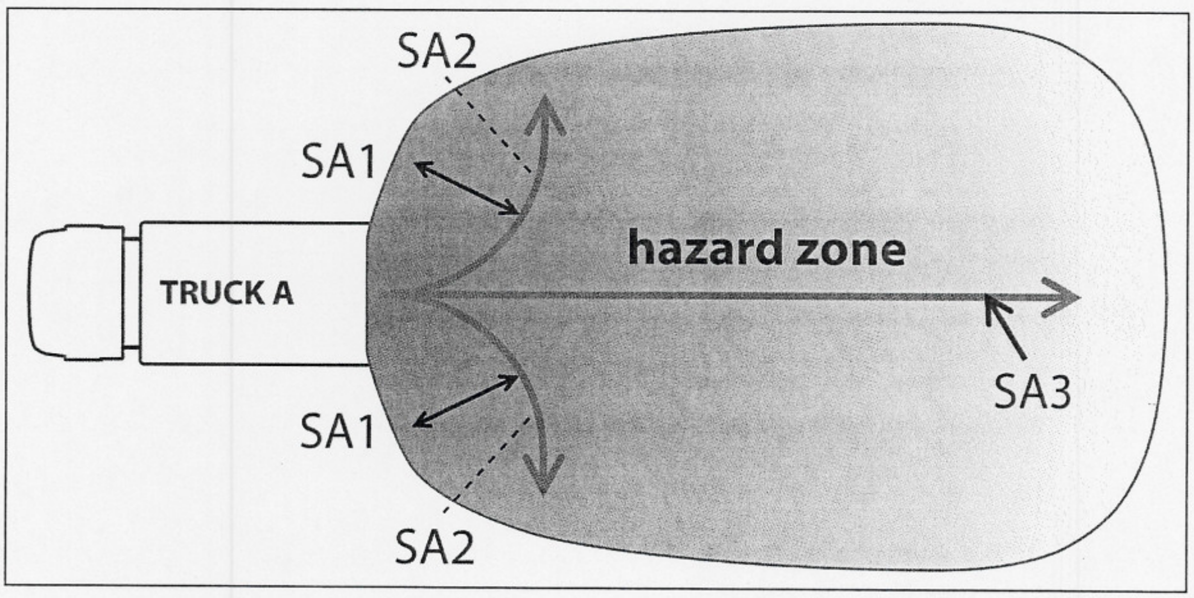

Figure 1 – Truck A (eg Wheel Loader)

Drawing illustrative, not to scale

Exhibit "A" - continued

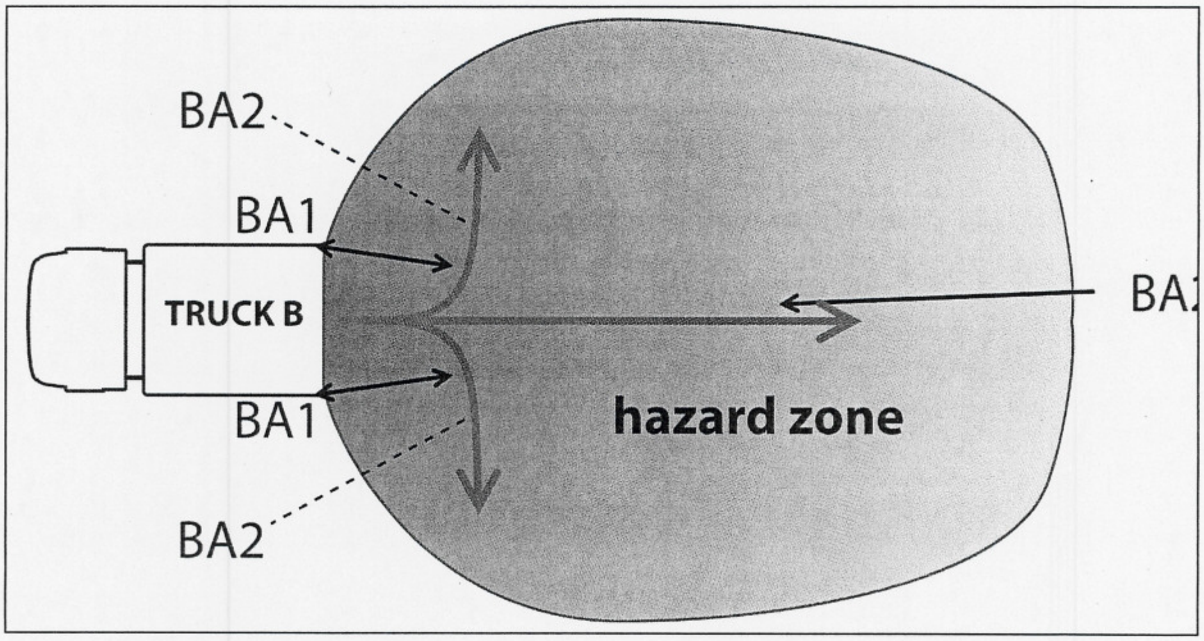

Figure 2 – Truck B (eg Concrete Truck)
Drawing illustrative, not to scale

Cal-OSHA Alarm Zone
200 Distance; Radius
1,256,000 Area; square feet

Zone Calculations
(Assume hazard zone is a circle)

Wheel Loader
88 Distance
44 Radius
60,790 Area; square feet

Road Truck
Assume hazard zone is a circle:
36 Distance
18 Radius
10,174 Area; square feet

Figure 3

For the purposes of approximation it is assumed that the hazard zone is a circle (this gives a lower "false alarm" and higher "response" rates).

Cal-OSH. The Cal-OSHA requirement of 200 feet gives a total zone of 1,256,000 square feet.

Wheel Loader. Based on a hazard distance of 88 feet to the rear of the truck and using this as the diameter to calculate the required warning area, the total hazard area is 61,000 square feet (over calculation).

Road Truck. Based on a hazard distance of 36 feet to the rear of the truck and using this as the diameter to calculate the required warning area, the total hazard area is 11,000 square feet (over calculation).

False Alarm Zones

Using the above hazard zones and based on the requirement for the back-up alarm must be heard at 200 feet the false alarm rates are 95% & 99%, making the response rates just 5% and 1% respectively as per Figure 4 below.

False Alarm Zones	Hazard Zone in sq ft	False Alarm Rate	Response Rate
Wheel Loader	60,790	95%	5%
Road Truck	10,173	99%	1%

Figure 4

Exhibit "B"

BBS White Paper Rev4 CONSULTATION DRAFT

Broadband Sound

The Safer & Noiseless* Alarm

A Brigade white paper - December 2007/Rev4 - DRAFT

* Webster Dictionary Definition of Noise; "any sound that is undesired or interferes with one's hearing of something". The sound from a correctly selected and installed broadband alarm is heard only in and near the danger area - where it is meant to be heard.

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Foreword

Sound, like birdsong for example, can be pleasant. Noise, by definition, is unpleasant. Vehicle alarm noise is everywhere these days, so much so that health suffers and some people are driven momentarily, literally, insane by it. Considerations of safety and health have been set on a collision course with each other. Something has had to be done. Broadband sound provides the answer

Broadband (white sound) alarms with their locatable sound were originally introduced to enhance safety, however their fitment has been driven primarily by the need to eliminate noise nuisance. Questions have been raised as to the unfamiliarity of the new sound. It has to be said that each and every type of audible warning has a first time for every living being on the planet. Should the first ever reversing alarm have been disallowed because it was unfamiliar? Or should all reversing alarms sound like the first one ? - which they definitely do not

Much of this paper was published in revision 3 (Rev3) and circulated to over 3,000 safety professionals; operations, safety & environmental managers; acoustic consultants and; NIOSH & MSHA. Covering correspondence requested comment on the paper. Without exception comments have been complimentary with recognition of the credibility and accuracy of the document. Changes to this revision include:

1. Layout. Following several requests, the layout now highlights the safety arguments
2. Recognition & Response. During Summer 2007 a company suffered two fatalities in two separate back-up accidents. In each case respectively the truck and mobile plant involved were equipped with fully functional and compliant tonal back-up alarms. The findings were that each victim had "tuned out" the tonal alarms. Appropriate response to a back-up alarm follows recognition of a danger signal. Response failure indicates the signal was filtered out as irrelevant back-ground noise or sub-conscious assumption that the sound originates from a truck backing up elsewhere.

Although this paper applies to all types of travel alarm it is directed specifically at back-up alarms.

Introduction

This paper sets out both the safety and the environmental benefits of broadband sound as applied to back-up alarms. The rationale for its adoption as standard fit on trucks, fork-trucks and mobile plant becomes self-evident

Evaluation of backup alarms and scientific research confirms that broadband sound is very effective at indicating the location of a sound source. In 2002 the American Council for the Blind called for the use of locatable sound saying current tonal alarms "serve more to disorient people who are blind and visually impaired than to assist them"[2].

"Noise seriously harms human health and interferes with people's daily activities at school, at work, at home and during leisure time". "Calling noise a nuisance is like calling smog an inconvenience" and "noise must be considered a hazard to the health of people everywhere" are frequently quoted comments by Dr. William H. Stewart, former Surgeon General of the USA.

In comparison to the conventional tonal (narrowband) back-up alarm, an equally loud bbs-tek® broadband sound back-up alarm is just as effective at alerting the listener to the presence of the reversing vehicle but, by contrast, is little heard outside the danger area. This significantly reduces noise nuisance and the risk of the alarm being ignored due to over familiarity[3].

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[2] American Council for the Blind resolution ACB 2002-22.

[3] New York State – Department of Health Case Report 03NY036; "Often people who work regularly near back-up beepers become accustomed to their sound and become desensitized to them as warning signals." http://www.health.state.ny.us/environmental/investigations/face/03ny036.htm

A comparative chart of the relative effectiveness in normal working environments between tonal and broadband back-up alarms is below:

	Factors (*Bad* v's Good)	Tonal	bbs
Safety	**Recognition:**		
	Loudness / Audibility	*An alarm with appropriate loudness should be installed*	
	Is Sound a Danger Warning	*Unlikely*	Yes
	Is the Danger Relevant	*Unlikely*	Yes
	Danger Locatability	*No*	Yes
	Response	*Poor*	Good
	Hard of Hearing - Audibility	*Risky*	Good
	Response	*Poor*	Good
	Locatability	*Very Poor*	Good
	Cause Confusion	*Likely*	Unlikely
Environ-mental	**Gets rid of noise complaints**	*No*	Yes
	Strident	*Yes*	No
Health	**Risk of hearing damage & stress**	*Greater*	Lower

Every measure of a back-up alarm's fitness-for-function shows that a broadband signal provides a superior warning than a tonal signal in terms both of safety, of health and of the environment.

Safety – Key Factors

Back-up alarms are fitted as devices to improve safety. Their function is to alert anyone who may be in the danger zone that the vehicle is backing so that a person recognizes the hazard and takes appropriate action to move out of harm's way. The danger warning signal needs to be heard in all parts of the danger zone. The danger zone is the area where a person is either in or could move into the travel path of the backing vehicle.

Back-up alarms are safety devices; model selection should be to maximize safety. For a back-up alarm to be effective (safe) it needs to fulfill two criteria:

1. **Recognition**. There are three elements to recognition:

   a. Loudness. The alarm must be loud enough to grab the attention of someone pre-occupied by a task. ISO-7731 defines the loudness required for danger warning signals.

   b. Is the sound a danger warning? The primary requirement for a back-up alarm's warning signal is a sound pattern which makes the signal message unambiguous[4]. SAE J994's definition is for the pattern to be between 0.8 to 1.8 Hz with the length of the on & off periods being within 20% of each other.[5]

   c. Is the danger relevant? False alarms must be minimized otherwise they become associated with the sound of a vehicle backing – elsewhere. . Low false alarm rates improve safety and worker/public acceptance, "False alarms negatively impact safety" [6]

2. **Response**. The alarm should demand immediate response by those in or close to the hazard area. Quicker response occurs when the sound source direction is instantly locatable.

[4] ISO 11429, 4.2
[5] SAE J994, Section 6.2; "Cyclic Pulsation Rate and Duty Cycle
[6] www.grc.nasa.gov/WWW/RT/2005/RI/RIS-hunter.html

Cross References:

A cross reference between key factors and contents of this paper is below:

Factors	Relevant Section	
Recognition	General	(page 13)
	Hard of Hearing – Better Recognition	(page 18)
Loudness	Audibility	(page 13)
	Audible Through Ear Defenders (Ear Protection)	(page 18)
	Reduced Risk of Alarm Sound Being Masked	(page 18)
Is the sound a danger warning Signal?	See ISO 11429, 4.2	
Is the danger relevant?	Sound Localised within Hazard Area	(page 14)
	Rapid Sound Dissipation	(page 18)
	Resonance	(page 17)
Response	False Alarms	(page 16)
	Response	(page 17)
	Locatable Sound	(page 13)
	Tonal Alarms Cause Confusion	(page 17)
Other Factors:		
Safety – other factors	End to Intentional Disconnects	(page 18)
	Reduced Risk of Alarm Sound Being Masked	(page 18)
Environmental	Rapid Sound Dissipation	(page 18)
	Less Irritating	(page 18)
	Tonal Aspect	(page 20)
	Resonance	(page 17)
Health	Introduction	(page 11)
	Reduced Risk of Hearing Damage	(page 19)
	Reduce Heart Risk due to 'Startle'	(page 19)

General

"The nature of the danger signal shall be such that people in the reception area can hear and react to the signal as intended. If persons with hearing impairment (deafness) or hearing protection (helmets, ear plugs, etc.) are likely to be present, special care should be taken. The characteristics of the audible signal shall be adapted to take account of the characteristics relevant to the situation." [7]

Audibility

"The danger signal shall be clearly audible. The effective masked threshold shall be distinctly exceeded. If relevant, the probability of hearing loss in the recipient population may be assessed and taken into account. If hearing protectors are worn, their levels of attenuation shall be known and introduced into the assessment." [8]

Locatable Sound

The American Council for the Blind reported at their 2002 annual Conference in Houston, Texas, that conventional alarms serve more to confuse blind people than to assist them and called for the use instead of locatable sound.

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[7] ISO 7731, 4.1

[8] ISO 7731, 4.2.2.1

Instant location of a sound-source is a part of Nature's survival mechanism. An animal in imminent danger of being attacked promptly locates the sound of the stalking predator by naturally occurring broadband sounds such as the crack of a breaking twig or the rustle of leaves which accurately reveals the approach direction of the danger.

To locate a sound source, three parts of the frequency spectrum must be heard simultaneously, as a single sound:

1. Low Frequencies; about 1KHz and below. With low frequencies the brain can process the time difference between the sounds arrival at one ear then the other.
2. Mid frequencies; about 3KHz and above. At frequencies above 3KHz (approx) the brain senses the intensity difference of the sound at each ear, i.e. the brain determines the ear receiving greater sound intensity is closest to the source. With this frequency range we can determine if the sound is to the left or right. These leave a 'cone of confusion' as illustrated in Figure 1 below.
3. Higher Frequencies; about 5KHz and above. Due to our outer ear shape and body shape, higher frequencies are modified before entering the ear canal. This is an individual response and is known as the HRTF (head related transfer function). This phenomenon is a learned skill and allows the brain to determine if the sound is to the front or rear.

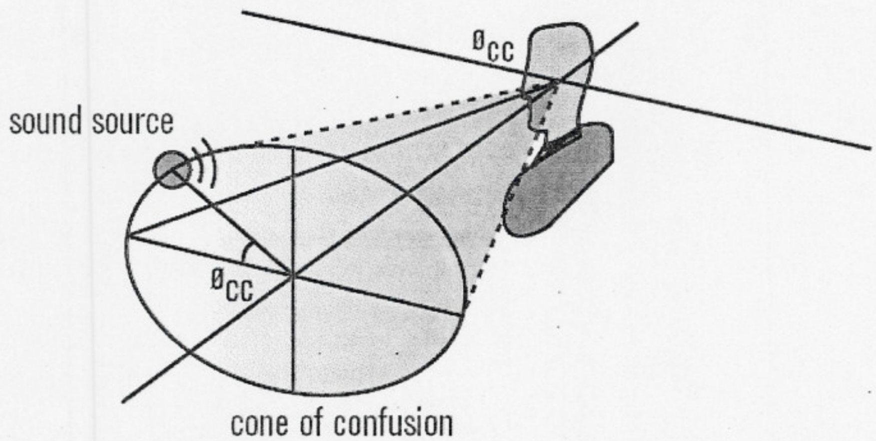

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Figure 1

With a large section of each of these frequency ranges the brain can locate the direction of the sound source. The more the better, and with broadband sound the accuracy of instant locatability is around 5 degrees.

Tonal alarms often create confusion in the work place. (See section – Tonal Alarms Cause Confusion.) Although tonal sound sources can sometimes be located by head rotation the process is unreliable, particularly in areas with reflective surfaces such as construction sites and street environments. Also, this process takes precious time and is sometimes only achieved with simultaneous sight cues.

Sound Localised within Hazard Area

Broadband sound is localised in and near the hazard area. This has two main benefits.

1. It gets rid of noise nuisance and complaints from those that do not need to hear the warnings.
2. Unlike tonal alarms which become "meaningless" [9], those exposed to danger are more responsive, because when a broadband sound alarm is heard the hearer knows they are in or close to a hazard area.

[9] Toyota Industrial Equipment booklet; 00698-20036-04 06TMH35158; with reference to tonal alarms - "Pedestrians become habituated to the alarm and ignore it, as it constantly sounds a meaningless warning."

How is this achieved?

There are a number of factors that contribute to this benefit.

1. Lower dBA output! Figure 2 below illustrates a tonal alarm and a broadband alarm that both measure 100dBA using a conventional sound meter to IEC 60651:1979 Class 2 or better. The maximum dBA output from the black-line tonal alarm is 100dBA whereas the maximum dBA output from any of the red-line broadband frequencies is about 10dBA lower! The distance a sound travels is dependent upon the peak frequency dBA output – not the conventional SPL meter reading!

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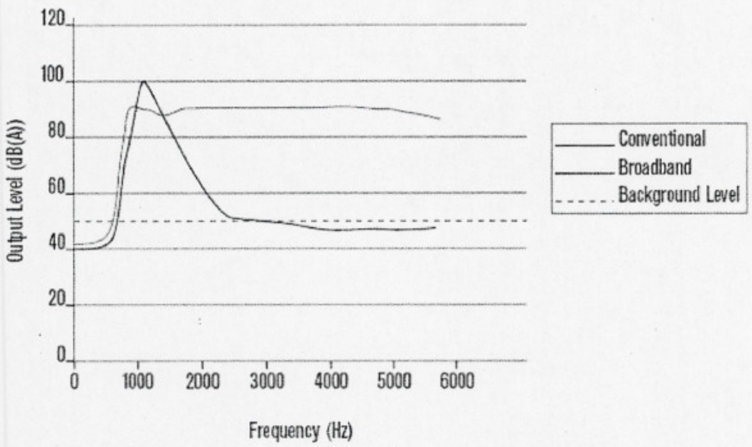

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Figure 2

2. Dissipation off-axis. Whereas a tonal alarm is omni-directional, broadband is focused into the danger area. The schematic at Figure 3 below recorded by Hanson Aggregates[10], is typical of several studies reviewing broadband sound dBA dissipation off the rear axis. While there is negligible sound dissipation in the danger area, there is a significant reduction of typically around 10 dBA area at 90 degrees to the side of the vehicle away from the danger area.

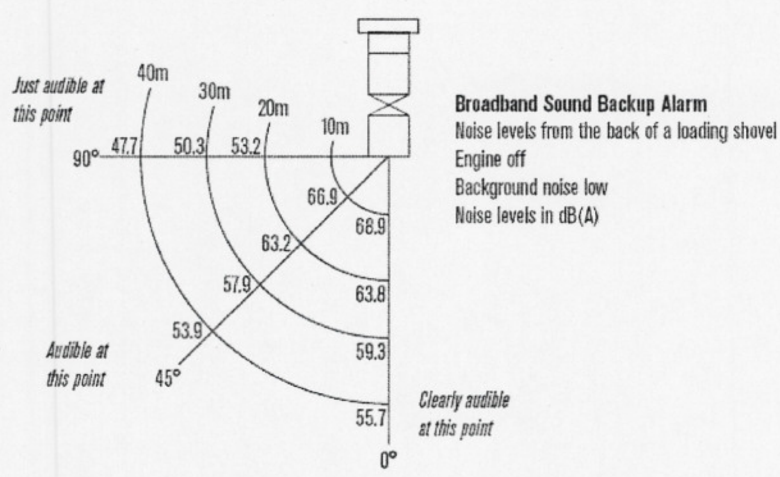

Figure 3

3. Lower dBA rating. Scientific analysis, has revealed that a broadband back-up alarm is equally effective at 5dBA lower SPL than a conventional tonal alarm[11 12]. This can be understood when considering the measurement of loudness as detailed in ISO-226:2003. Figure 4 below shows the typical broadband (red box) and tonal (blue line)

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10 Tom Hill, Environmental Manager, Hanson Aggregates, Whatley Quarry; drawing dated 15 July 2002

11 Martin Lever, HS&E Manager RMC (Cemex); verified results of 150 subjects at South East Quarries Liaison Safety Day 2003.

12 UK Health & Safety Executive report "Improving the safety of workers" Contract Research Report 358/2001.

alarm regions. In the critically audible range of around 1kHz to 4kHz the tonal alarm sounds at the frequency that is least audible to the human ear; i.e. tonal alarms operating in this range require to be about 5 dBA louder for equal audibility. This, plus the fact that the individual frequencies of a broadband alarm peak at about 10dBA lower, making a total reduction of around 15dBA.

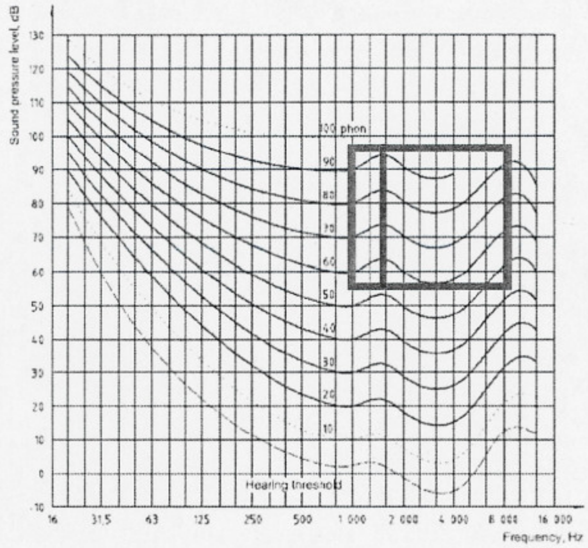


Figure 4

Net Effect of These Factors

Aggregating these three factors reveals broadband sound's full potential as a noise-abater. Roughly speaking, a 6dBA reduction of the sound source yields a halving of the sound travel distance. The schematic at Figure 5 below shows: (The theoretical impact areas represented as a percentage of the tonal impact area is shown in brackets.)

1. Black Outer Circle. The range of noise impact of a tonal alarm 'X' (100%).
2. Blue disc. Sound impact area of a broadband alarm with the same dBA output to 'X' if it did not have the off-axis, away from the danger area, localised characteristic (10.2%).
3. Mauve disc. Alarm zone of broadband with same dBA rating as tonal alarm 'X' (3.4%).
4. Red Area. The alarm zone should the tonal alarm 'X' be replaced by a 5dBA lower broadband alarm (0.9%).

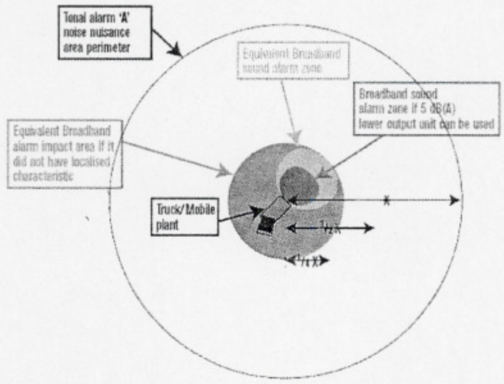


Figure 5

False Alarms

A false alarm is an alarm that is heard by someone outside the danger zone.

Response

False alarms are of no use to anyone, serving only to increase the noise levels within that environment. With regard to safety, they will over time become less effective as people (sub-consciously) match their response level to the false alarm rate.[13] For example, alarms which are genuine for 90% of the time produce response rates close to 100%, as people will respond in accordance with the warning's accuracy. If a warning is only 10% genuine, people will respond only 10% of the time. False alarms are costly both in terms of annoyance and of performance.[14]

False alarm rates for tonal alarms are unacceptably high.

Resonance

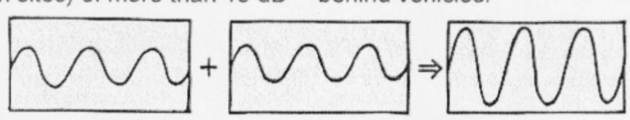
A tonal alarm can resonate with truck (or other metal) panels. This resonance increases noise levels, sound-source confusion, , environmental noise nuisance and loss of respect as an alarms

The level of increase can be quite dramatic, 5 dBA[15] for a garbage truck and over 20 dBA[16] on a fork truck

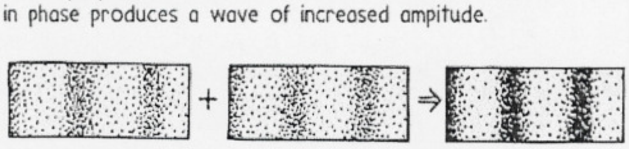
Tonal Alarms Cause Confusion

Whilst broadband sound is locatable, of great concern is the confusion caused by tonal alarms –there is a simple explanation:

The problem with tonal alarms results from the well known acoustical phenomenon of standing waves. The typical back-up alarm has a frequency of around 1.25 KHz and at this frequency the wavelength is 10.85 inches. Back-up alarms contain a speaker that, when radiating a tone, moves in and out at a constant rate (frequency) to produce the sound. As it moves out it compresses the air in front of the speaker, as it moves back it rarefies the air; when these compressions and rarefactions reach the ear they push and pull the ear drum and so we hear the sound. When a tonal alarm emits its "beep" these compressions and rarefactions travel both directly to and invariably via one or more reflections to the ear. If the difference in distance between two paths of the alarm sound travel is a multiple of the alarm wavelength then the compressions combine and intensify and for a good reflection this increases the sound pressure by 3dBA (See Figure 6 below). Similarly, if the path difference is ½ the wavelength then, for a good reflection, the compression and rarefaction cancel each other out and no sound is heard! "Reflections of these sound waves on the ground or diffraction by the sides of vehicles have the effect of reducing or even cancelling them before reaching the listener. Within spaces of less than a few inches, Laroche and Lefebvre found variations in sound pressure level (on construction sites) of more than 15 dB[17] behind vehicles."[18]



The superposition of two identical transverse waves in phase produces a wave of increased ampitude.



The superposition of two identical longitudinal waves in phase produces a wave of increased intensity.

Figure 6

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13 Bliss et al, 1995.

14 Edworthy Judy, Hellier Elizabeth; Auditory warnings in noisy environments

15 Goeff Leventhall: Noise Measurements on Garbage Truck and Back-Up Alarms

16 Tony Gardner: Ibstock Bricks Lodge Lane Factory noise exposure study 2004

17 **Laroche, C., and L. Lefebvre**: Determination of optimal acoustic features for reverse alarms: Field measurements and the design of a sound propagation model. Ergonomics 41:1203–1221 (1998).

18 **Alice H Suter**: Construction Noise: Exposure, Effects, and the Potential for Remediation; A Review and Analysis - AIHA Journal (63) November/December 2002. This Suter paper can be accessed on http://www.cdc.gov/elcosh/docs/d0100/d000054/d000054.html

Although a tonal back-up alarm emits a frequency that does not enable the sensing of the subtle intensity difference required to locate a sound source[19], there are invariably much larger intensity differences due to reflections. The listener assumes the greater intensity of sound in one ear is due to that ear being closer to the sound source – which is not the case; the greater intensity being due to standing wave pressure differences.

What's more; as the listener's head turns towards what was assumed to be source the intensities vary in these few inches without any relevance to the sound source direction – compounding the confusion. This confusion caused by tonal alarms is not possible with broadband alarms. Why? Because a broadband alarm operates over a wide range of frequencies with wavelengths from less than 2 inches to more than 17 inches and while a frequency analysis will show frequency intensity variations due to standing waves the overall intensity remains constant.

Audible Through Ear Defenders (Ear Protection)

Low frequencies more readily penetrate solid objects. When music is played very loud in a building or car with windows and doors shut, it is the low frequencies boom-boom noise that is heard. The low frequencies can travel through the body and are heard through many ear defenders. Fog horns use low frequencies because they travel long distances, round corners and penetrate solids such as windows, walls etc.

Hearing protectors tend to be much better at attenuating some frequencies than others. So, broadband alarms with both low and wide range of frequencies are more likely to be heard than a tonal alarm when ear protection is used.

Reduced Risk of Alarm Sound Being Masked

Tonal travel alarms are at risk of being masked by similar frequency background noise. Broadband almost entirely eliminates this risk.

Rapid Sound Dissipation

Broadband sound's massive frequency spectrum enables lower overall SPL. While it's low frequencies travel further they are more benign whereas the less tolerable high frequencies are more readily absorbed by air. As a result the overall sound pressure reduces more quickly with distance from source.

Less Irritating

Tonal alarms are more strident and irritating than broadband frequencies. (See Technical Stuff; Psychoacoustics & Tonal Aspect sections below).

End to Intentional Disconnects

Many companies suffer increased danger, breached regulations and repair costs following sabotage of tonal alarms. Broadband alarms however, are comfortable to work with and their extra safety benefits are respected as well.

Hard of Hearing – Better Recognition

The cochlea (inner ear) is a long 'string' of receptors, akin to a ticker tape. Each receptor receives within a narrow frequency range. Hearing impairment is generally restricted to those receptors which are damaged. Figure 7 below shows the cochlea receptor frequencies aligned with the travel alarm frequencies. In this case, the damaged receptors correspond with the whole of the tonal alarm's frequency band which is therefore unheard. Conversely, all the other frequencies of the broadband are heard perfectly well.

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[19] See section "Locatable Sound, 2. Mid Frequencies.

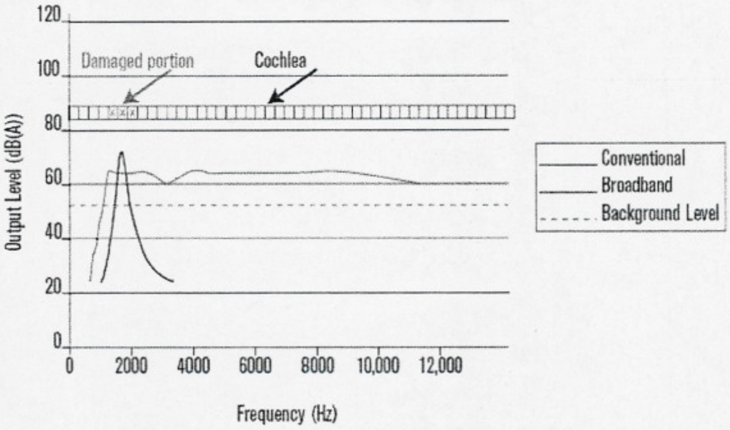

Figure 7

Reduced Risk of Hearing Damage

With lower frequency output for the same tonal sound pressure reading, the risk of hearing damage is greatly reduced.

Reduce Heart Risk due to 'Startle'

ISO-7731 states; "Reactions due to fright (e.g. more than 30dB in 0.5 seconds) may be caused by using too high a sound-pressure level." We would add "these can also delay, or even prevent escape from danger due to 'freezing'".

The risk of shock/startle is much less likely using broadband travel alarms with their lower SPLs and multi-frequencies.

Technical Stuff

Equal SPL measurements and Spectral analysis

A reading of sound pressure on an SPL meter (as per ANSI S1.4 (or IEC 60651) – specification for sound level meters) will 'average' the sound pressure in each frequency band and present a consolidated single figure output - weighted as per the settings on the dBA meter.

It is the industry norm to measure SPL using the 'A' weighting dBA which adjusts the correct measurement of SPL to the actual response of the human ear. This 'A' weighting adds or subtracts a number of dB from the level reading from each of the frequency bands in order to simulate the non-linear output versus the frequency response of the ear.

The graph at Figure 8 below shows the SPLs which might be expected from a conventional travel alarm (when centered on 1250Hz) and a broadband travel alarm. Clearly the frequency content of broadband is much larger than tonal, but always at a lower SPL. These SPLs could be read using a sound meter (and filter set) as per ANSI S1.4 & S1.11 (or IEC 60651 & 61260) set to the one third octave range.

Although the broadband shows lower SPLs in each one third octave band the added effect of these is equal to the tonal travel alarm - 100dBA at 1m.

The summation of decibels is as follows:-

$$SPL^{R} = 10\times\log(10^{[spl1/10]} + 10^{[spl2/10]} + 10^{[spl3/10]} \ldots)$$

where spl1, spl2, spl3 etc., are the individual one third octave band sound pressure levels.

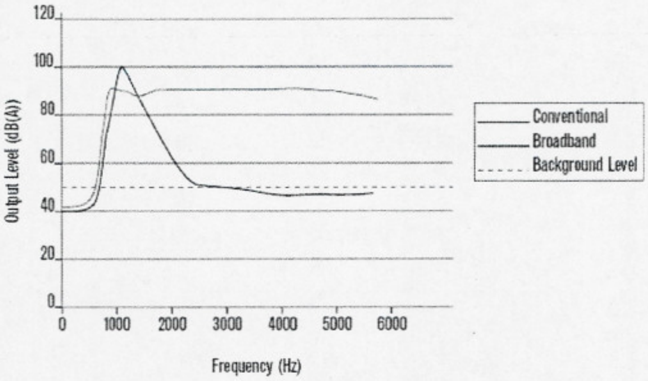

Figure 8

Sound versus Distance

In a free field (open 3D spherical space) sound dissipates from a point source according to an inverse square law and the reduction in dB is calculated as:-

$$SPL^{R} = 10x\log\left[{}^{1}/_{r^2}\right]$$

Where 'r' is the distance of the listener from the source. This results in the well known 6dB drop for each doubling of distance from the source. However, most sound sources are not 'ideal point sources' and hence have less than ideal sound distribution in every direction.

Hence, taking into account no other environmental factor the SPL will be about 36dB lower in each one third octave band for a listener 60m from the source. Ref. to the graph in Figure 8 we can see that this 36 dB lower SPL at 60m from the sound source means that broadband SPLs have dropped almost to ambient SPLs whereas the tonal travel alarm remains some 10dBA above ambient.

The rate of sound-absorption depends on numerous other features including frequency content. Air absorbs sound faster (i.e. more rapidly per doubling of distance) in the higher frequency ranges. Atmospheric conditions (humidity, temperature, wind direction and speed etc.) all affect the speed of sound. The rate of sound absorption by physical structures between source and listener (buildings, fences, trees etc.) is also frequency dependant.

Psychoacoustics

The perception of sound is what is judged to be 'pleasant' or 'intrusive'. Sensitivity is greater and sounds therefore seem louder in the 1KHz to 4KHz band (this forms the basis for the 'A' weighting system). Discrete tonal alarm noise is intrusive even in high ambient noise levels.

Tonal Aspect

The 'Tonal' aspect is important enough for the Federal Aviation Administration to have made provision for the presence of "tones" in aircraft noise in the Federal Regulation for Noise Standards on Aircraft. (Title 15 - Aeronautics and Space, Chapter 1, part 36.803 - Noise evaluation and calculation). The FAA penalizes tonal content by nearly 7 dBA.

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Exhibit "C"

Fault Tree Analysis